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DEVELOPMENT OF POWER OPERATED SEMI AUTOMATIC STRAW BALER

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ABSTRACT

An experimental manual operated strawbaler was developed to determine the effect of moisture content (11 % and 19 %), straw length (300 mm and 600 mm) and compression force (372, 490 and 589 N) on bale density of paddy straw. The optimised parameter was taken for design, development of a power operated semi automatic straw baler and its performance was evaluated. The physical properties such as straw size, moisture content and bulk density of paddy straws (ADT 36) were determined using standard procedures. A maximum volume reduction of 6 times could be achieved by using developed power operated semi automatic straw baler. The cost of the bailing using the machine was Rs. 800 per ton.

KEYWORDS: Bale Density, Paddy Straw Baler, Straw Management, Physical Properties, Densification

INTRODUCTION

In India, paddy crop is cultivated about 43.97 million ha with a production of 104.32 million tonnes during 2011-12 (Ministry of Agriculture, 2012). About 1 to 1.77 kg of paddy straw is produced per kg of grain harvested (Thirunavukkarasu, 2011) and thus, approximately 104.32 million tonnes of paddy straw is estimated to be produced annually. Pathak *et al.* (2010) estimated that about 500 million tonnes of crop residue is generated in every year. In this, Paddy straw alone contributes about 22 per cent of the total crop residue and 30 per cent of total cereals crop residue. The surplus amount of paddy straw estimated in total crop residue was 44 Mt, which is mostly burnt on-farm. The available surplus paddy straw can used as dry fodder for feeding of livestock without burning. The requirement of dry fodder for livestock is increasing every year. The scarcity of feed resources is one of the major constraints impacting to livestock development and low productivity. The deficit gap of availability and the requirement of dry fodder are 138 MT (23.46 per cent) in 2010. There is a huge demand of paddy straw for livestock feed in future. Recovery of on-farm burning paddy straw will reduce the deficit of dry fodder up to 32 per cent (Thirunavukkarasu, 2011).

The major barrier against the use of these bulky residues as feedstock was due to their collection, handling, transportation and storage. Baling is a process of reducing the material volume to achieve a defined package which facilitates handling and preserves material quality for future use. Baling the rice straw into rectangular or round bales is the important step in handling rice straw for animal feeding and other applications such as, fuel and fibre for paper manufacturing. In India, the concept of large round bales could not make any impact owing to scattered and small areas of rice field. Small hay balers to be popular because harvesting losses are lower than large round balers. Additionally, the use of a small rectangular baler was shown to be more profitable than the use of a large round baler (bales stored outdoors) in a simulation study of a dairy farm (Rotz *et al.*, 1989).

The baler helps to save the paddy straw from weather calamities, makes handling and transportation easier, facilitates its easy and safe storage and maintains its quality. At present straw baler available is self propelled with high horse power. These machines are not economic for small and marginal farmers of Indian farming. There is a need of small machine that can be used by small farmers.

Kepner *et al.*, 1987 described that hay was handled from the field as bales and densities of baled hay were generally varied from 130 to 225 kg m^{-3}. Rectangular bales were easier to transport than round bales since there was little risk of the bale rolling off the back of a flat bed trailer. The rectangular shape also saved space and allowed a complete solid slab of hay to be stacked up for transport.

Teffera, 2002 studied advantage of compressed hay press over the traditional method. The average pressing rate, bale density, and baling time of the horizontal type press were 36.9 kg hr^{-1}, 72.3 kg m^{-3} and 17.4 min per bale respectively.

Sandhya *et al.*, 2007 conducted an experiment for evaluating the performance of the commercial rectangular baler in the rice field. The test was conducted at 12.73 per cent moisture content in wet basis and the initial density of straw was found 16.67 kg m^{-3}. The bale density attained was varied from 130-200 kg m^{-3} and compaction ratio was found to be 7 to 10.

MATERIALS AND METHODS

The paddy straw variety (ADT 36) after threshing with two different threshers was selected for bailing. The experiment was conducted in wetland farm located in Tamil Nadu Agricultural University, Coimbatore, India.

STRAW PROPERTIES

The crop properties, relevant to the design of baler components were identified as the length and diameter of straw, moisture content and bulk density of paddy straw.

LENGTH OF PADDY STRAW

Paddy straw was selected at random after threshing and its length and diameter were measured with vernier caliper after placing it on a horizontal platform in its natural rest position.

WEIGHT OF SINGLE PADDY STRAW

One bunch of paddy straw was selected randomly and each straw weighed by using an electronic balance having a sensitivity of 0.1 g.

MOISTURE CONTENT

Moisture content was determined using an oven drying method. An aluminium dish was weighed using a digital balance. The sample was placed in the dish and the dish and sample were weighed. The dish and sample were then placed in an air-forced drying oven and kept at 105°C until a constant weight was achieved. The dish containing the dried sample was cooled to the room temperature in desiccators and then weighed. The moisture content was calculated on a wet basis as follows

$$\text{MC} = \frac{Ww - Dw}{Ww} \times 100$$

Where,

MC = Moisture content in per cent (w.b)

W_W = Wet weight of the sample and dish, g

D_W = Dry weight of the sample and dish, g

BULK DENSITY OF PADDY STRAW

One cubic meter drum was taken, cleaned and weighed in an electronic balance. The drum was filled up to rim with the paddy straw and the material was slightly compacted to ensure absence of large void spaces. The container and the sample were weighed. The bulk density of paddy straw was calculated as follows:

$$\rho_b = \frac{W_2 - W_1}{V}$$

Where,

ρ_b = Bulk density of paddy straw, kg m^{-3}

W_1 = Weight of empty drum, kg

W_2 = Weight of drum + paddy straw, kg

V = Volume of drum, m^3

The procedure was repeated for 11 per cent and 19 per cent moisture content. Each time, test was replicated five times and the average value was taken as bulk density.

EXPERIMENTAL MANUAL OPERATED STRAW BALER UNIT

An experimental manually operated straw baler unit was constructed to investigate the effect of compression force on bale density. The component of the experimental manual operated straw baler was feed hopper, compression chamber, plunger, connecting rod and hand lever. The overall dimension of the manually operated straw baler is 1775 × 980 × 200 mm and is depicted in Figure 1.

Figure 1: Experiment Manual Operated Straw Baler

FEED HOPPER

To uniformly feed the straw into the bale chamber, an inclined feed hopper was fitted above the bale chamber. The capacity of the feed hopper for holding the straw was 0.005 $m^{3.}$ The shape, slope and size were determined based on physical properties of the crop. The hopper is made up of 18 gauge mild steel sheet having 220 mm opening in top and 150 x 120 mm opening at the inlet.

BALE CHAMBER

The bale chamber was made up of 16 gauge mild steel sheet and 25 × 25 × 6 mm mild steel ‘L’ angle. A single mild steel sheet was bent as rectangle with inlet and outlet opened. The edge of bale chamber was attached with ‘L’ angle to give strength for bale chamber. The dimensions of the chamber were 900×200×200 mm. Two slots were provided in middle of the bale chamber face for knotting the compressed straw. The length and height of the slot were 250 mm and 30 mm. The bale chamber provided with extension frame on both sides with square pipe, to place the unit gently on the horizontal surface.

PLUNGER

Rectangular type teak wood of 80 x 200 x 200 mm was used for the construction of the plunger. Plunger was placed inside the feeding side of the bale chamber. The bale chamber cover acts as a guide for sliding of plunger. One face of the plunger was connected with connecting rod using plunger pin and other face left plain to compress the straw.

HAND LEVER

Hand lever was made up of 25 x 25 mm hollow square pipe. The length was adjustable as 780, 980 and 1200 mm from the ground level. At the top end of the lever, force is applied manually by hand and bottom end was mounted in bale extension frame with cotter pin.

CONNECTING ROD

Connecting rod was made of 25 x 25 mm hollow mild steel square pipe. It was connected to the centre of the

plunger using plunger pin and at a height of 200 mm from ground. It transfers the force applied in hand lever to plunger. The length of the connecting rod was 450 mm.

EXPERIMENT PROCEDURE

Experimental manual operated straw baler was tested by compressing the straw through hand lever. Three hand lever heights, two level of moisture content and straw length were taken for the test. The different heights of hand lever taken were 780, 980 and 1200 mm. The moisture contents and straw length used for baling were 11 and 18 per cent and 300 and 700 mm respectively. The density of loose paddy straw bale was weighed and readings were recorded. Initially 11 per cent moisture content of paddy straw and 780 mm hand lever height was used for conducting trial. The straw was fed through feed hopper into bale chamber inlet. Straw was compressed by plunger into bale chamber. Inside the bale chamber, compressed straw was knotted by twine using slots provided. The bale was separated by wood, inserting inside through feed hopper for every ten stroke of plunger. Knotted bale was collected at outlet of the bale chamber. Load cell was fitted at the connecting rod to measure the force required for making different bale density. In each treatment, five replications were carried out. The obtained bales density and force required for bale were calculated and reading was recorded. The lever arm height was change to next level (980 and 1200 mm) with same moisture content and straw length above experiment was carried out. Similarly for 12 per cent moisture content and 700 mm straw length at three levels of hand lever height, the above procedure was repeated and the observations were recorded.

LEVELS OF VARIABLES

The levels of variables selected for investigating the bale density using an experimental manual operated straw baler are furnished below.

- **Moisture Content** **-** 2 levels
  - 11 per cent - (M_1)
  - 18 per cent - (M_2)
- **Lever Arm Height** - 3 levels
  - 780 mm (38 kg) - (A_1)
  - 980 mm (50 kg) - (A_2)
  - 1200 mm (60 kg) - (A_3)
- **Straw length -** 2 levels
  - 70 cm - (S_1)
  - 35 cm - (S_2)
- **Replications** **-** 3 levels

Total number of treatments = M x A x S x R

= 2 x 3 x 2 x 3 = 36

EFFECT OF SELECTED LEVELS OF VARIABLES

A total number of 36 experiments were conducted using experimental unit with selected levels of variables. The bale density obtained from different compression force was calculated. The effect of selected levels of variables on the evaluation parameters were analyzed statistically.

EXPERIMENTAL DESIGN

Statistical analysis was done with Factorial Completely Randomized Design (FCRD) and three factors ANOVA was laid out. The factors considered and their levels are furnished in Table 1.

Table 1: Design Layout of FCRD Experiment

Sl. No.	Parameters	Variables	Levels
1	Factors	Lever arm height (Compression force)	X_1
		Moisture content	X_2
		Straw length	X_3
2	Dependence variables	Bale density	Y_1

AGRES (v. 7.01) developed by Pascal Intel System was used to analyze the data. This was done to obtain the necessary analysis of variance of the main and interaction effects of variables on the bale density.

$Y_1 = f(X_1, X_2, X_3)$

The compression force at which maximum bale density obtain was calculated and based on that, selection of motor hp was done for construction of power operated semi automatic straw baler.

RESULTS AND DISCUSSIONS

Straw Properties

The mean length of ADT 36 variety paddy straw after threshing with two different threshers was 600 and 300 mm and the diameter was 4.3 mm. The mean moisture content of ADT 36 variety paddy straw immediately after threshing and after 2 days open sun drying was 19 per cent and 11 per cent. The average weight of single paddy straw of ADT 36 variety paddy straw at 11 per cent and 19 per cent moisture content was 0.93 g and 1.13 g respectively. The average bulk density of ADT 36 paddy straw at 11 per cent and 19 per cent moisture content was 19 and 22 kg m^{-3} respectively.

Bale Density

The effect of compression forces on the bale density of paddy straws for moisture content (11 and 19%) and straw length (300 and 700 mm) was shown in Figure 2 and Figure 3. The bale density of paddy straw increased linearly with the increase in compression force for both straw lengths. A similar relationship of bale density with compression force was reported for paddy straw by Ferrero et al. (1990). Regression Eq. 1 and Eq. 2 were obtained for bale density using MS Excel at 700 mm and 300 mm straw length. It was observed that the 300 mm straw length had larger bale density than 700 mm straw length.

$y = 18.519x + 56.173$

$R^2 = 0.9992$ ------------------------------- (1)

$$y = 19.815x + 56.296$$

$$R^2 = 0.9935 \text{ -------------------------------} \quad (2)$$

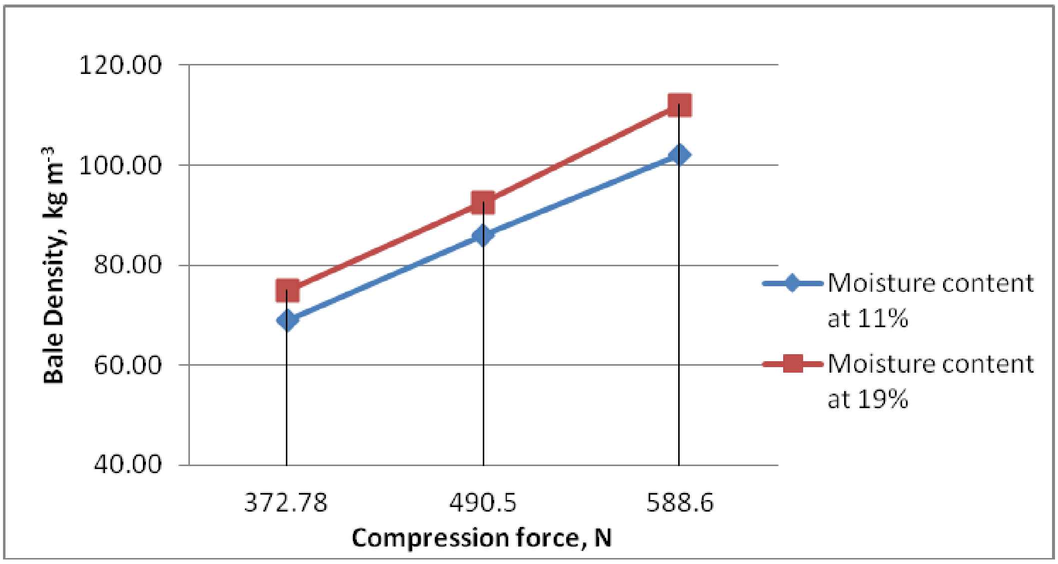

Figure 2: Relationship between Compression and Bale Density of Paddy Straw at 700 mm Straw Length

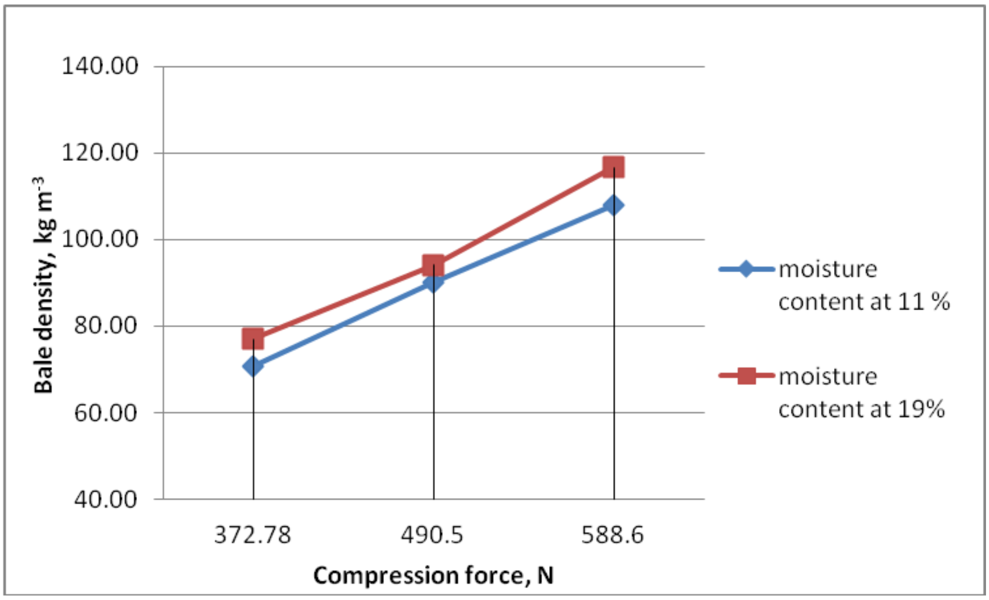

Figure 3: Relationship between Axial Load and Bale Density of Paddy Straw at 300 mm Straw Length

The effects of compressive force, straw length and moisture content on bale density were analyzed using AGRES by analysis of variance (ANOVA). Table 2 shows that the ANOVA for factors affecting on paddy straw bale density. Compressive force (F), straw length (S) and moisture content (M) and their interaction had significant effect on bulk density ($P \geq 0.05$). The statistical analysis of paddy straw showed that the best treatment for bailing the straw using experimental manual baler was 1200 mm of lever arm height (measured compression force was 588.6 N) and 19 per cent moisture content.

Table 2: Analysis of Variance (ANOVA) for Factors Affecting on Bale Density

Source	Df	SS	MS	F	PROB
Treatment	11	14469.224058	1315.384005	730.4588	0.000**
F	2	13518.202803	6759.101402	3753.4632	0.000**
M	1	710.360042	710.360042	394.4770	0.000**
S	1	157.496402	157.496402	87.4609	0.000**
F x M	2	44.126743	22.063372	12.2522	0.000**
M x S	1	4.134375	4.134375	4.2959	0.000**
F x S	2	30.093523	15.046762	8.3558	0.000**
F x M x S	2	4.810170	2.405085	4.3356	0.000**
Error	44	79.233617	1.800764	1.0000	

POWER OPERATED SEMI AUTOMATIC STRAW BALER

The calculated force for get the maximum bale density of 112 kg m^{-3} was 70 kg. To improve the bailing capacity and efficiency, a power operated semi automatic straw baler unit was developed (Figure 4) by attaching one hp motor and performance evaluation was carried out. The developed prototype baler consists of feed hopper, bale chamber, plunger and connecting rod same as that of manual operated straw baler. Transmission system was developed to reduce the motor speed from 1440 rpm to 13 rpm by attaching belt and pulley and bevel gear reduction unit (20:1).

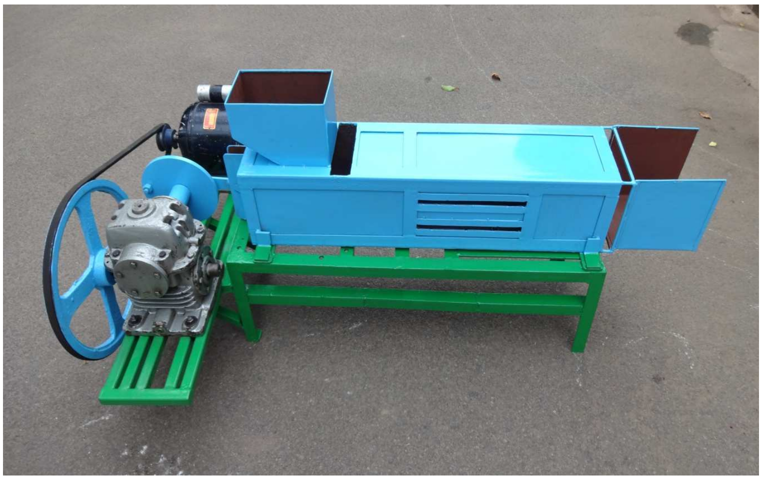

Figure 4: Developed Power Operated Semi Automatic Straw Baler

PERFORMANCE EVALUATION OF POWER OPERATED SEMI AUTOMATIC STRAW BALER

The field performance studies with the developed power operated semi automatic straw baler were carried out for two varieties (ADT 36 and ASD 18). The total bale volume and weight, average bale density, baling capacity and compaction ratio was given in Table 3. The total bale volume and weight of ADT 36 was 0.126 m^3 and 16.24 kg and ASD 18 was 0.125 m^3 and 15.8 kg respectively. The average bale density of ADT 36 and ASD 18 paddy straw was found to be 129 and 127 kg m^{-3}. The bailing capacity was 50.97 and 49.27 kg hr^{-1} for ADT 36 and ASD 18. Compaction ratio (CR) indicated the reduction in volume as a result of compression, which indicated the savings in transportation and storage by the same factor of volume reduction. Compression ratio was found to be app. 6 for both varieties, indicating that densification into bales saved up to 6 times of the storage, transportation space and costs.

Table 3: Field Performance of Power Operated Semi Automatic Straw Baler

S. No	Description	Value	
		ADT 36	ASD 18
1	Number of bales	10	10
2	Total bale volume, m^3	0.126	0.105
3	Total bale weight, kg	16.24	15.8
4	Initial density of straw, $kg\ m^{-3}$	21	20
5	Average bale density, $kg\ m^{-3}$	129	127
6	Baling capacity, $kg\ hr^{-1}$	50.97	49.27
7	Compaction ratio	6.14	6.35

Figure 5: Measuring of Bale Weight

CONCLUSIONS

A power operated semi automatic straw baler was developed for small and marginal farmers which can bale one ton paddy straw in two days by a single person. Volume of paddy straw could be reduced up to 6 times by compression into bale. The maximum bailing capacity and bale density obtained was 50.97 kg hr^{-1} and 129 kg m^{-3}. Cost of bale formation was found to be Rs. 800 per ton.

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